

DATA GENERATION FOR THE NUMERICAL SIMULATION OF POWDER COMPACTION

J.M. PRADO^{1,2}, M.D. RIERA^{1,2}

(1) CTM Centro Tecnológico. Manresa. Spain. (2) Dpto. Ciencia de los Materiales. Universidad Politécnica de Cataluña. Spain

Abstract. Numerical simulation of industrial plastic deformation processes needs of a precise characterization of the mechanical material properties included in the particular elastoplastic model. The plasticity model of bulk metallic materials is well known and the tests used for characterization are simple and well typified. The situation is quite different when the compaction of metal and ceramic powder has to be simulated; in this case, both, plasticity models and the corresponding mechanical tests are under discussion and research. Irrespective of the plastic model being employed more parameters and more complex than in the case of bulk materials must be determined. In this work the experience gained in this field by the joint effort of the research groups participating in the recently finished European Network Dienet is presented.

Keywords: powder compaction, numerical simulation, data generation

1. Introduction

Computer simulation of industrial processes such as forging, rolling, casting and welding is becoming a widespread tool in industry. It is based in the knowledge of the physical models and constitutive equations controlling the elasto-plastic and solidification behaviour of metallic alloys. The complex practical problem is solved by using one of the commercial finite element codes already existing.

In the case of the Powder Metallurgy, the simulation of the process is in an initial stage due to the lack of knowledge of an elasto-plastic model that could explain the mechanical behaviour of porous sintered components. The lack of mechanical models is even greater when the initial stage of powder die compaction is the one to be simulated. In this latter case, plasticity is usually modelled by using geological models such as Drucker-Prager and Cam-Clay [1, 2]. The tests needed to characterize the mechanical properties used in the simulation of conventional bulk materials are well known and established, but this is not the case when porous and, in general, granular materials are considered. The parameters to be determined change with the elastoplastic material model used, besides there is not enough work in literature and the little that can be found leads frequently to contradictory results.

In this work the experience gained in this field by the joint effort of the research groups participating in the recently finished European Network Dienet is presented.

2. Elastoplastic models

Two are the models more widely used: Cam-Clay and Drucker-Prager Cap. In spite that the Cam-Clay model is much simpler than the Drucker-Prager is this latter one the more used by researchers. The original model uses two yield surface segments: a pressure dependent Drucker Prager shear failure surface and a compression cap yield surface. The failure surface is perfectly plastic in the sense that no mechanical strain hardening occurs, but plastic flow on this surface produces inelastic volume increase; in other words, for states of stress on this surface the sample dilates under constant applied stress. The equation describing this failure surface is:

$$f_1 = q - p \tan \beta - d = 0 \quad (1)$$

where q and p are the deviatoric and the hydrostatic stresses, respectively; β is the angle of friction, and d is the cohesion of the material. The shape of this surface on the p - q space is, then, a straight line.

The cap yield surface has an elliptic shape in the p - q plane and hardens (expands) or softens (contracts) as a function of the volumetric plastic strain: volumetric plastic compaction (yielding on the cap) causes hardening, while volumetric plastic dilation (yielding on the shear failure surface) causes softening. The equation describing the cap yield surface is

$$f_2 = [(p - p_a)^2 + (Rq)^2]^{1/2} - R(d + p_a \tan \beta) \quad (2)$$

p_a is an evolution parameter, related to the hydrostatic compression yield stress p_b , that represents the volumetric hardening or softening, and R is a material parameter that controls the shape of the cap. All these features of the yield surface are shown in Fig. 1.

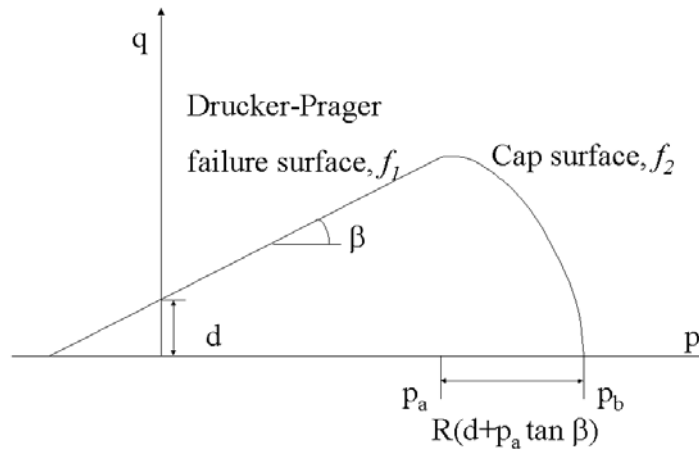


Fig. 1. - Drucker-Prager/CAP model

The failure line can be easily determined by means of two relatively simple tests: uniaxial compression and Brazilian tests [3,4].

The three parameters (R , p_a and p_b) defining the Cap can be found by means of only one compression test carried out in an instrumented close die [6]. Close die test allows to follow the state of stress (P_0 , Q_0) as function of density, (P_0 ,

Q_0) is located on the yield Cap of the corresponding density. The following three equations are used to find the necessary parameters:

$$\begin{aligned} 0 &= [(P_0 - p_a)^2 + (RQ_0)^2]^{1/2} - R(d + p_a \tan \beta) \\ p_b &= p_a + R(d + p_a \tan \beta) \\ R^2 &= (2/3)(P_0 - p_a)/Q_0 \end{aligned} \quad (3)$$

To complete the characterization of the material it is necessary to determine its elastic behaviour. This is normally done by load cycling inside the instrumented die and measuring elastic axial stresses and strains. The following assumptions are usually taken:

- Lineal elastic behaviour, with the elasticity parameters only dependent on density
- To solve the elastic strain-stress equations is necessary to assume a value for the Poisson coefficient.

In spite of the apparently simple picture presented the research groups working in this field find consistently different results for the same materials and properties. Fig.2 shows how the Cap model determined by A. Cocks and the CSM [6] for a Zirconia powder differs appreciably. No obvious reasons for this different behaviour have been yet proposed.

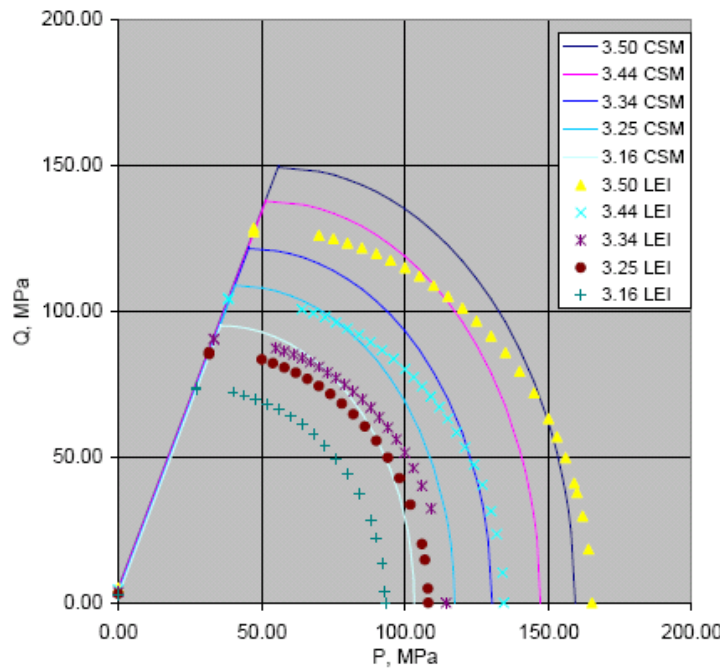


Fig.2 Comparison Cap model surfaces from LEI and CSM

3. Reasons for discrepancies

Two kind of possible causes for discrepancies between the results of researchers are going to be analysed: Experimental and theoretical.

3.1 Experimental problems.

There are two ways of measuring radial stresses in instrumented dies either using pressure sensors or by means of strain gages.

The use of force transducers is more reliable, as the sensors receives direct excitation of the powder, but is more complicated experimentally and expensive. Strain gages have been widely used and they allow to measure stresses at different heights of the compression length. The main problem with strain gages in this application is to have a good calibration. There are two problems for obtaining a reliable calibration: One is the wall thickness and the other is the non-homogeneous distribution of the circumferential deformation.

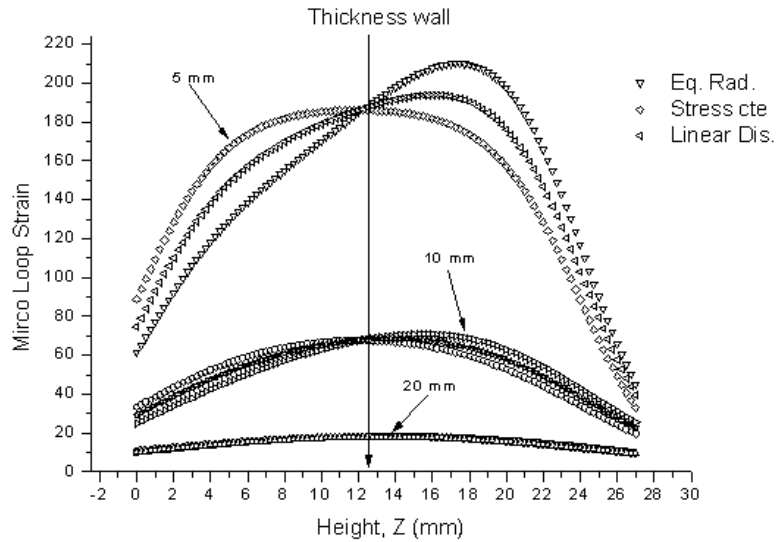


Fig.2. FEM simulation of circumferential strain with different radial stress distributions.

A FEM simulation of the circumferential strain in a cylindrical die under different radial strain distributions is shown in Fig.2. It is clear that the wall thickness it is very important to obtain deformations allowing enough gage sensitivity. A wall not thicker than 5 mm is recommendable. It is also important to point out that the place where the maximum deformation is located changes with the type of stress distribution. It only coincides with the middle of the die in the case of an uniform radial distribution. This is what occurs during the calibration with a liquid but not during the posterior powder compaction. Therefore to place the strain gage in the middle of the die will usually leads to erroneous results.

3.2 Theoretical problems

3.2.1 Elastic behaviour

To measure the Elasticity modulus from elastic loadings and unloadings in the compacting instrumented die needs always of a previous knowledge of the Poisson's coefficient even in thick walls dies for which no radial deformation could be assumed. The only way to find the Young modulus is by uniaxial compression tests of previously compacted samples to a given density. Done in this way the elastic behaviour is not lineal but it changes with applied load following a potential law of the type [7]:

$$\sigma_{ax} = K \varepsilon_{ax}^{3/2} \quad (4)$$

$$E = d\sigma_{ax}/d\varepsilon_{ax} = (3/2) K \varepsilon_{ax}^{1/2} = (3/2) K^{2/3} \sigma_{ax}^{1/3} \quad (5)$$

The effect of density is included in the constant K.

3.2.2 Plastic behaviour

As it has been stated the Drucker-Prager plasticity model is the one usually employed to simulate powder compaction it is a continuum mechanics model applied to a really micromechanical problem. It is worth to check its validity in a simple case.

A simple array of circles (Fig.3) has been submitted to different paths of loading

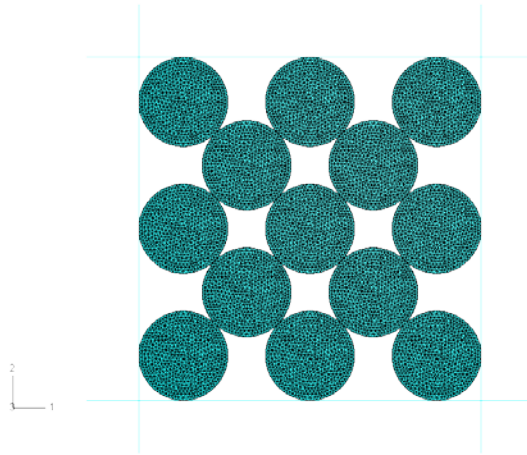


Fig.3 Array of circles meshed

To simplify the calculation a plane strain state has been assumed. The practical meaning is that the circles represent cylinders of infinite length perpendicular to the drawing plane. The material has been supposed to be low carbon steel and typical mechanical properties have been used for the FEM simulation.

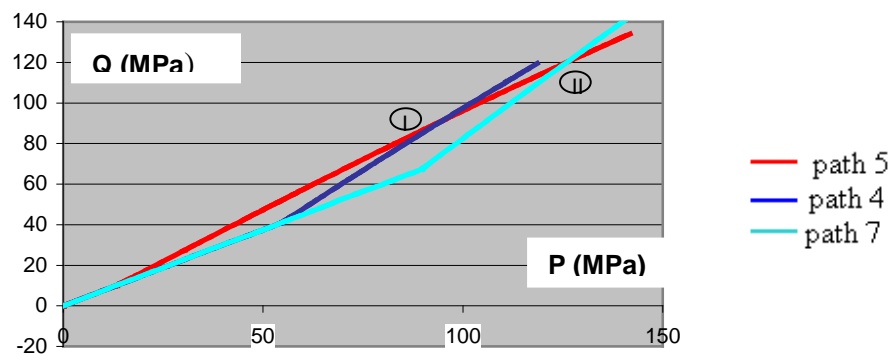


Fig.4 Loading paths

The Fig.4 shows the three loading paths studied and how path 5 intersects with paths 4 and 7. At the intersections points paths have the same state of stress and, consequently, they should give place to arrays of the same density. Table I give the deviatoric and hydrostatic components of the intersection points with the densities obtained

Table I

Intersection	P(MPa)	Q (MPa)	Area (mm ²)	Density (Mg/m ³)
Path 5	95.04	91.44	56.62	5.79
Path4	95.04	91.44	56.80	5.77
Path 5	125.91	119.95	51.54	6.36
Path 7	125.91	119.95	52.54	6.24

In spite that loading paths are not very different (Fig.4) the density values obtained change. The variation is more appreciable the higher are P and Q. This is a confirmation that densification is path dependant and therefore there is not a unique plastic “yield locus” for each density.

4. Conclusions

Causes that can give place to differences in the data generated for computer numerical simulation are:

- Incorrect calibration of instrumented dies
- No applicability of theoretical models

5. References

- [1] D.C. Drucker, W. Prager. Soil mechanics and plastic analysis or limit design. Quarterly of Applied Mathematics, vol 10, no 2, p 157-175, 1952
- [2] DiMAGGIO, F.L. and SANDLER, I. Material model for granular soils. Journal of the Engineering Mechanics Division. ASCE. Vol. 97, Pg. 935-950, 1971
- [3] M.D. RIERA, J.M. PRADO. Uniaxial compression tests on powder metallurgical compacts. Proceedings of 1998 PM World Congress. CD-Document No. 615. Granada (Spain)
- [4] M.D. RIERA, J.M. PRADO, A. LARSSON. Determination of green strength of powder metallurgical compacts by means of the Brazilian test. Proceedings of 2000 Powder Metallurgy World Congress. Part II. Pp 1617-1620. Ed. Koji Kosuge and Hiroshi Nagai. Kyoto (Japan).
- [5] P. DORÉMUS, C. GEINDREAU, A. MARTIN, R. LÉCOT and M. DAO . High pressure triaxial apparatus for investigating the mechanical behaviour of metal powders. Powder Metallurgy World Congress PM' 94. Proceedings. Vol. I. Pg. 733. Paris (France).
- [6] CSM Report No. 11973R: European Network Dienet. 2005
- [7] J.M. PRADO, M.D. RIERA. Modelling of elastic behaviour of metal powder compacts. NATO Science Series III. Computer and Science Systems Vol. 176, pp. 63-70